N87-16398

TECHNICAL PROGRESS IN SILICON SHEET GROWTH UNDER DOE/JPL FSA PROGRAM 1975-1986

MOBIL SOLAR ENERGY CORPORATION

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Topics of Presentation

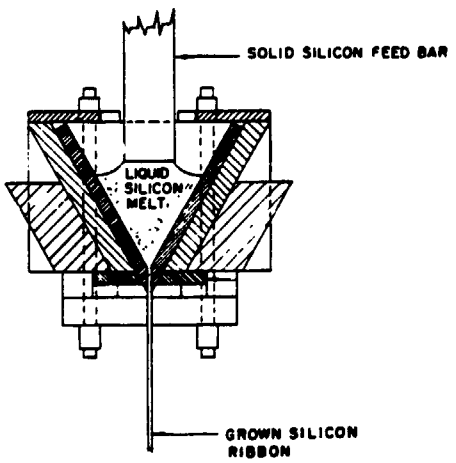
- SILICON SHEET TECHNOLOGIES - THEN AND NOW:
  - 1975-77: TECHNOLOGICAL FEASIBILITY STUDIES
  - 1978-80: PROCESS SELECTION
  - 1981-86: ECONOMIC FEASIBILITY DEMONSTRATIONS
- FUTURE POTENTIAL/R&D REQUIREMENTS

Sheet and Ingot Technologies Supported Under ERDA/FSA Programs 1976-1986

	1976	1980	1986
Sheet	EFG (Mobil Tyco)	EFG (Mobil Solar)	EFG (industry; full scale pilot plant)
	CAST (IBM)		
	Inverted Stepanov (RCA)		
	Web Dendritic (U. of S. Caroline)	WEB (Westinghouse, 1977)	WEB (industry; start-up pilot plant)
	RTR (Motorola)		
	SOC (Honeywell)	SOC (Honeywell)	
	CVD-Glass (Rockwell)		
	CVD-Si (GE)		
	Hot Forming (U. of Pennsylvania)		
		LASS (EMC, 1979) (SERI)	(Available to industry)
		Vaccum Die Casting (ARCO, 1979)	
		ESP (Ciszek, 1979) (SERI)	
		ESR (Sachs, 1979) (SERI)	(Available to industry)
Ingots	HEM (Crystal Systems)	HEM (Crystal Systems)	(Industry; material for sale)
		Advanced CZ (HAMCO/KAYEX, 1977)	(Industry; equipment for sale)
		" (Siltec, 1977)	
		" (Texas Instruments, 1977)	
		" (Varian, 1977)	
		Ingot Casting (UCP) (Semix, 198[illegible])	(Industry)

Technical Progress/Results 1975-1977
Process Selection 1978-1980

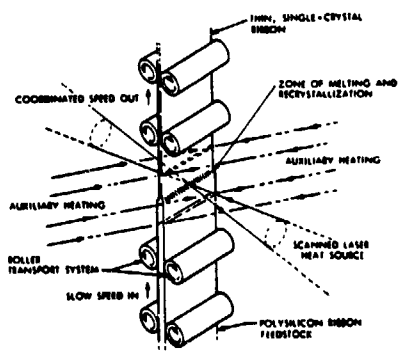
Inverted Stepanov



FEASIBILITY NOT DEMONSTRATED

- SUITABLE DIE MATERIAL NOT FOUND.
- PROCESS STABILITY NOT DEMONSTRATED

Ribbon-to-Ribbon (RTR)



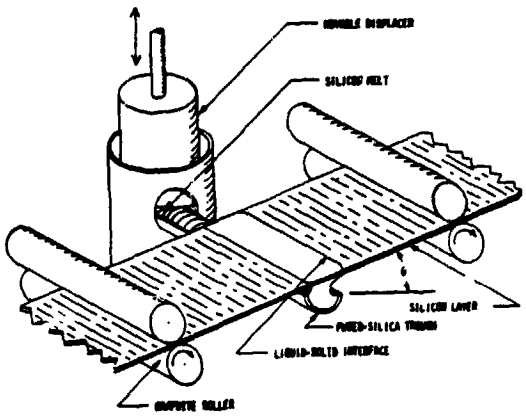
ACCOMPLISHMENTS

- CONTINUOUS GROWTH OF 5 CM WIDE RIBBON UP TO 25 CM LENGTH OF FEEDSTOCK DEMONSTRATED IN MULTIPLE RIBBON FORMAT UP TO 5-7 CM/MIN.

CONCERNS

- SUPPLY OF SUITABLE POLYRIBBON FEEDSTOCK.
- FEEDSTOCK WITH SUBSTRATE CONTAMINATION.

Silicon on Ceramic (SOC)

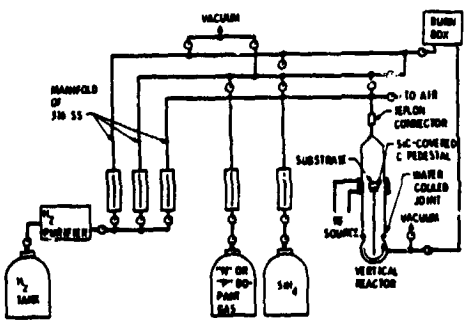


FEASIBILITY NOT DEMONSTRATED

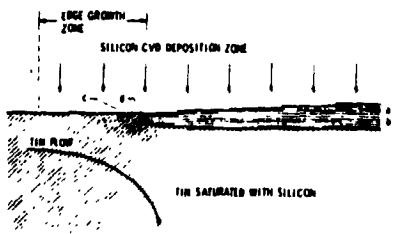
- SUBSTRATE MATERIAL CONTAMINATION NOT UNDER CONTROL.
- DIMENSIONAL CONTROL OVER LARGE AREAS (10 CM WIDE) AT HIGH SPEEDS (30 CM/MIN) A PROBLEM.
- HIGH SPEEDS OF 10-20 CM/MIN AND SMALL GRAINS MAY IMPAIR EFFICIENCY (USUALLY LESS THAN 10%).

Chemical Vapor Deposition (CVD)

GLASS SUBSTRATE



SI-SN SYSTEM

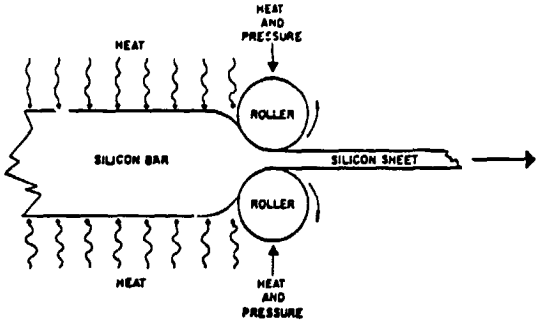


FEASIBILITY NOT DEMONSTRATED

- NO GEOMETRICAL CONTROL OF SHEET DIMENSIONS.
- GRAIN SIZE TOO SMALL, NUCLEATION UNCONTROLLED.

Hot Forming

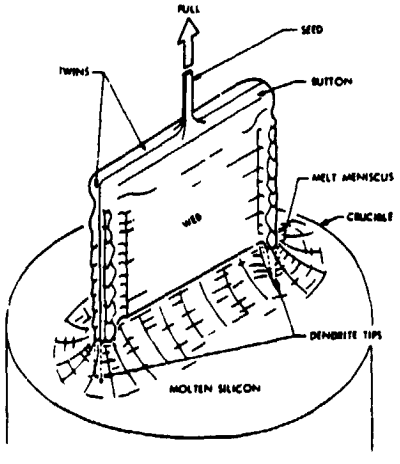
PROCESS: I. COMPRESSION OF POLYSILICON.
II. ANNEAL TO INCREASE GRAIN SIZE.



FEASIBILITY NOT DEMONSTRATED

- LARGE GRAIN RECRYSTALLIZATION TOO SLOW.
- CONTAMINATION EFFECTS UNDETERMINED.

WEB Dendritic (WEB)



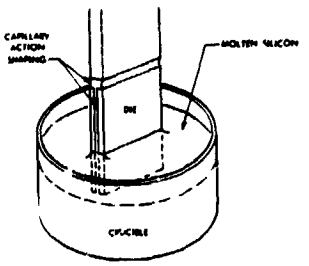
ACCOMPLISHMENTS

- CONTINUOUS GROWTH OF WEB OF 3 CM WIDTH, AT 1-2 CM/MIN AND 150 MICRON THICKNESS MADE ROUTINE IN SINGLE RIBBON FURNACES. MELT REPLENISHMENT DEMONSTRATED.
- MAXIMUM EFFICIENCIES OF 15%.

CONCERNS

- LONG TERM STABILITY/REPRODUCIBILITY.
- GROWTH SPEED/WIDTH (AREAL RATE) LIMITATIONS COMMON TO ALL VERTICAL SHEET GROWTH TECHNIQUES.

Edge-Defined Film-Fed Growth (EFG)
Capillary Action Shaping Technique (CAST)



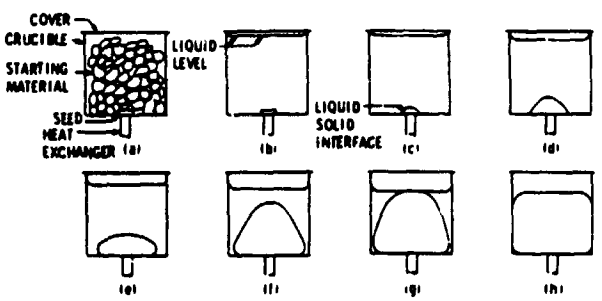
ACCOMPLISHMENTS (EFG)

- CONTINUOUS GROWTH OF UP TO 10 CM WIDE RIBBON UP TO 3 CM/MIN AND 250 MICRONS THICKNESS IN MULTIPLE (x4) MACHINE FORMAT/MELT REPLENISHMENT MADE ROUTINE.
- AVERAGE CELL EFFICIENCIES OF THE ORDER OF 9% (NO H_2 PASSIVATION).

CONCERNS

- MULTIPLE MACHINE COMPLEXITY, MATERIAL INHOMOGENEITY HAMPER ROUTINE OPERATION AND REPRODUCIBILITY.
- HIGH H_{EFF} EFG (CARTRIDGE CONCEPT) OPERATES CLOSE TO REGION OF THERMO-CAPILLARY INSTABILITY.
- DIE MATERIAL REACTIVITY.
- VERTICAL EFG LIMITED TO 2-3 CM/MIN GROWTH SPEED BY CREEP
  - AREAL RATE LIMITATION COMMON TO ALL VERTICAL SHEET GROWTH TECHNIQUES.

Heat Exchanger Method (HEM)



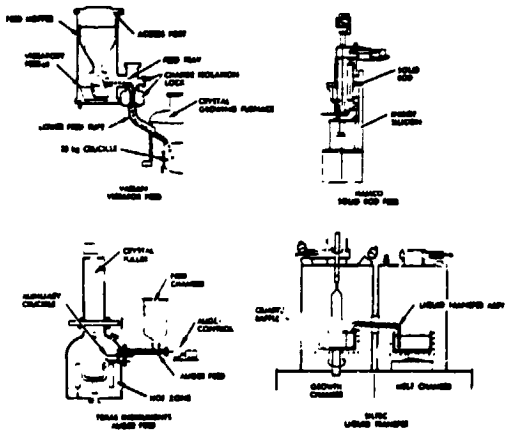
ACCOMPLISHMENTS

- LARGE SINGLE CRYSTAL INGOT (33 x 33 x 18 CM^3, 45 KG) SOLIDIFICATION DEMONSTRATED AT 1.25 KG/HR.
- HIGH (90%) SINGLE CRYSTAL YIELD, HIGH (UP TO 15%) EFFICIENCIES.

CONCERNS

- IMPROVED SLICING TECHNIQUES WITH INCREASED SPEED, REDUCED KERF LOSS NOT AVAILABLE.
- HIGHER SINGLE CRYSTAL YIELDS (PERFECTION) OBTAINED AT SLOWEST SOLIDIFICATION RATES.

Continuous Czochralski



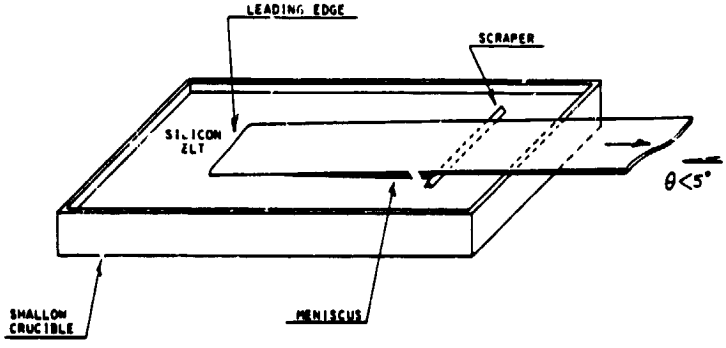
ACCOMPLISHMENTS

- MULTIPLE INGOT GROWTH ESTABLISHED (150 KG), UP TO 15 CM DIAMETER.

CONCERNS

- REDUCED YIELD DUE TO POLYCRYSTALLINITY.
- FEASIBILITY OF HIGH THROUGHFUT WAFERING.
- THROUGHPUT LIMITS IN RANGE 1.5 KG/HR.

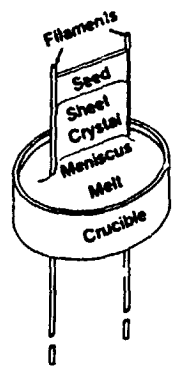
New Developments 1978-1981
Low-Angle Silicon Sheet (LASS)



FEASIBILITY NOT DEMONSTRATED

- GROWTH RATES OF 30-60 CM/MIN ACHIEVED FOR SHORT LENGTHS.
- THICKNESS/DENDRITE CONTROL PARAMETERS NOT ESTABLISHED.
- LONG TERM GROWTH STABILITY UNTESTED.

Edge Supported Pulling (ESP)
Edge Stabilized Ribbon (ESR)



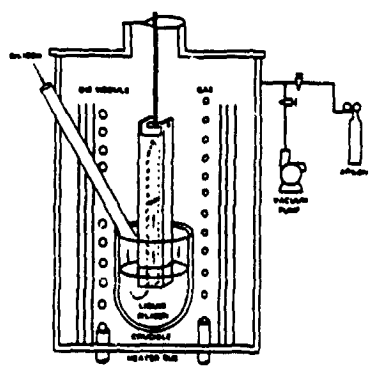
ACCOMPLISHMENTS

- PROCESS STABILITY/EDGE DEFINITION FOR RIBBON GROWTH ACHIEVED WITHOUT NEED OF DIE.

CONCERNS

- LONG TERM GROWTH REPRODUCIBILITY.
- IMPACT OF EDGE STABILIZERS ON QUALITY, YIELD.
- GROWTH SPEED/WIDTH (AREAL RATE) LIMITATIONS COMMON TO ALL VERTICAL SHEET TECHNIQUES.

Vacuum Die Casting

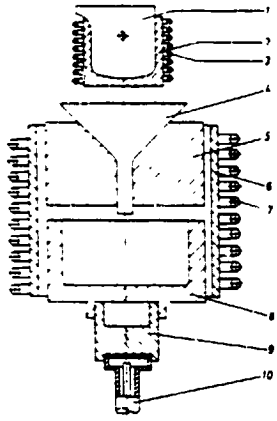


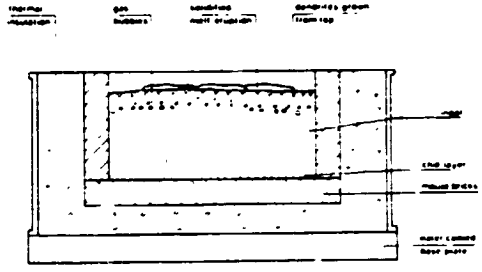
ARGON PRESSURE INJECTION OF LIQUID SILICON INTO THE DIE CAVITY

FEASIBILITY NOT DEMONSTRATED

- MOLD CONSTRUCTION MATERIAL A PROBLEM.
- STRESS CONTROL PARAMETERS UNDETERMINED, GRAIN NUCLEATION NOT CONTROLLED.

SEMIX Ingot Casting (UCP)





(WACKER PROCESS ILLUSTRATIONS: HELMREICH ET AL. 1980, 1982)

ACCOMPLISHMENTS

- SOLAR CELL EFFICIENCIES OF 13-14% OVER 100 CM^2 AREAS.
- 20 CM X 20 CM X 10 CM INGOTS.

CONCERNS

- THROUGHPUT LIMITATIONS DUE TO CONSTITUTIONAL SUPERCOOLING.
- MATERIAL INHOMOGENEITY (PROCESS YIELD).
- WAFERING RATE AND KERF LOSS FACTORS.

Silicon Sheet Technologies 1986 and Beyond

EFG
(CLOSED SHAPE POLYGONS)

WEB
(SINGLE RIBBON)

AND

INCLINED INTERFACE SHEET GROWTH

LASS - EMC (USA)

RAD - CGE (FRANCE)

HSW - SIEMENS (W. GERMANY)

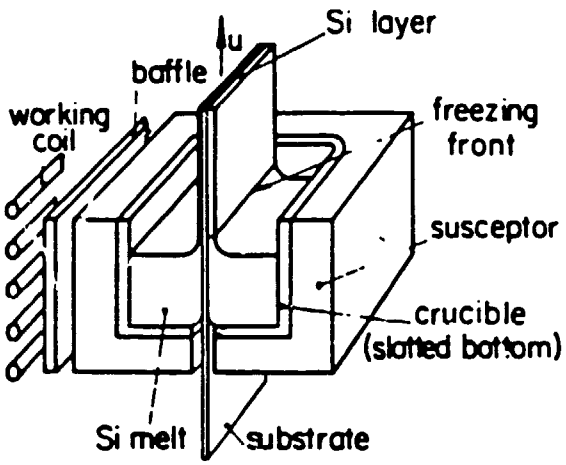
RQ - TOHOKU (JAPAN)
- ARCO (USA)

RAFT - WACKER (W. GERMANY)

ALL SINGLE RIBBON TECHNIQUES

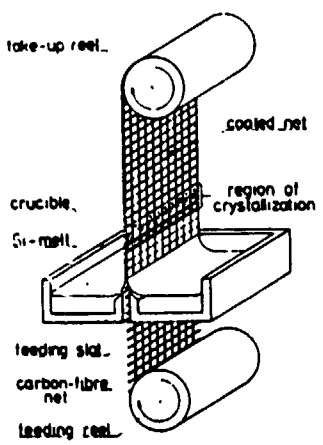
High Throughput Single Ribbon
RAD (CGE)

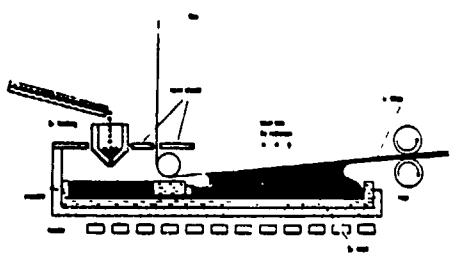
5 CM WIDE X 10 CM/MIN



High Throughput Single Ribbon
HWS (Siemens)

6 CM WIDE X 100 CM/MIN





1986 Status/Future Potential
EFG
(Closed Shape Polygons)

Status
- Areal output of current nonagon at (9) x (5 cm wide x 2.2 cm/min) = 100 cm^2/min.
- Large (~45 cm^2) cell efficiencies of 13-15%.
- Best cell (45 cm^2) is 15.1%.

Concerns
- Cutting/yield limitations (material strength).
- Improvements in passivation of microdefects.
- Productivity limitations due to stress and die material deterioration.

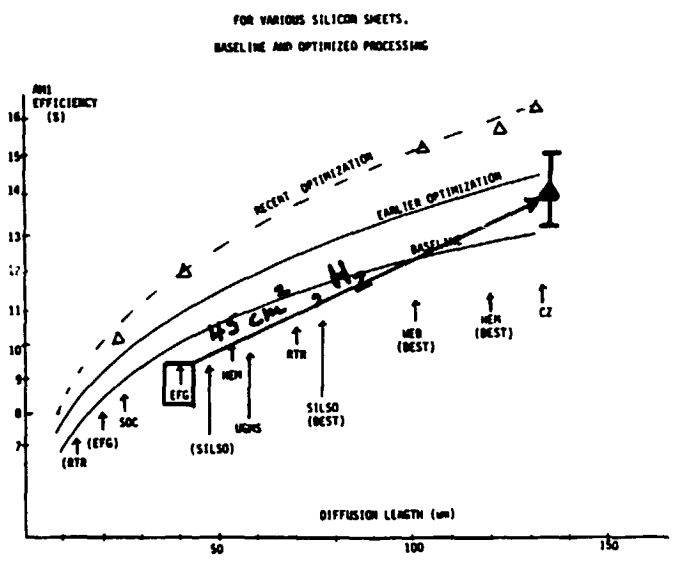
1986 Status/Future Potential (Cont'd)
WEB
(Single Ribbon)

Status
- Areal output of single crystal furnaces at 4 cm wide x 1.5 cm/min = 6 cm^2/min (8.5 cm^2/min best).
- Large batch (~25 cm^2) cell efficiencies best average 14%.
- Best cell (4 cm^2) 17.3%.

Concerns
- Areal output limitations may be below 10 cm^2/min for best (>16%) cells.
- Long term growth stability.

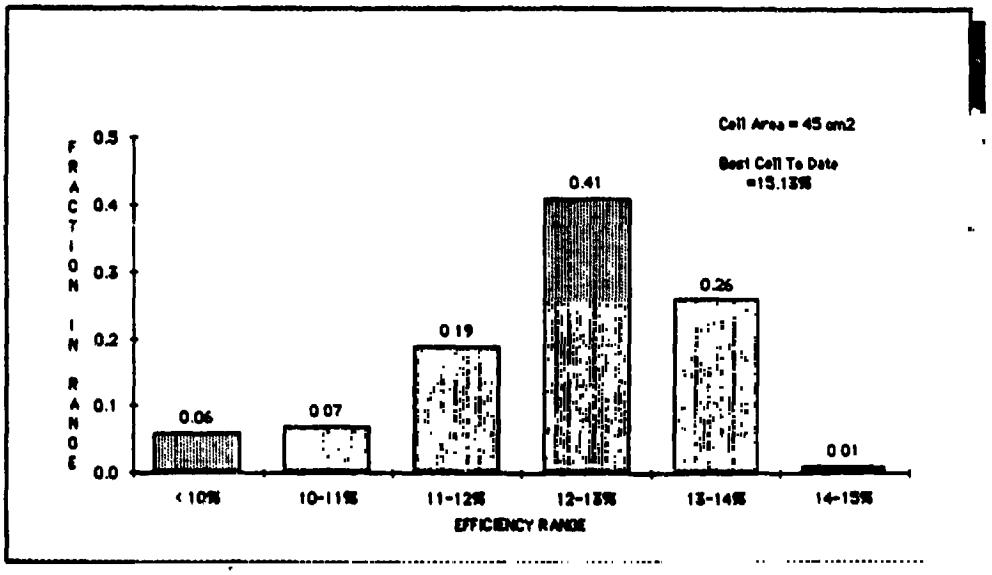
Large-Area Silicon Sheet Task

AM1 Efficiency vs Diffusion Length



ASEC - 16TH PIM, SEPTEMBER 1980

Current Cell Efficiency Distribution
(Mean Value = 12.21%)



Key R&D Requirements to Meet Potential

- UNDERSTANDING OF RECOMBINATION EFFECTS OF BASIC SILICON MICRODEFECTS AND PASSIVATION SCHEMES TO ACHIEVE 200-300 MICRON DIFFUSION LENGTHS CONSISTENTLY OVER LARGE AREAS.
- ACHIEVEMENT OF MEANS TO INCREASE HOMOGENEITY AND STRENGTH OF SILICON SHEET MATERIAL TO MAXIMIZE PROCESSING YIELDS.
- UNDERSTANDING OF INCLINED INTERFACE SOLIDIFICATION PROCESSES IN SPEED RANGE OF 5-100 CM/MIN
  - SINGLE RIBBON AREAL RATES UP TO 1000 CM^2/MIN MAY BE POSSIBLE.